Columbia University
in the City of New York

LAMONT GEOLOGICAL OBSERVATORY
PALISADES, NEW YORK

Technical Report No. 8

CU-18-55-TO24 - Geol.

Bearing Determinations for Sofar Type Signals Using Two Hydrophones

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BEARING DETERMINATIONS FOR SOFAR TYPE SIGNALS USING TWO HYDROPHONES

by

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ABSTRACT

A series of underwater TNT shots fired along an arc 120 miles off Bermuda is used to calibrate two hydrophones as a bearing determination system for SOFAR type signals. The hydrophones do not constitute a matched system. They are located sixteen miles apart. Bearing determinations are possible in the arc S.E. of Bermuda to an accuracy of 1.5°. Use of the system to determine bearings of distant shots is demonstrated.

INTRODUCTION

SOFAR is a name that may be applied collectively to long range acoustic signalling in the deep ocean. The sound propagation depends primarily upon the natural sound channel. It was originally described and discussed in detail by Ewing and Worzel (1948).

Two hydrophones were installed by the Columbia University Geophysical Field Station, Bermuda off the S. E. shore of Bermuda for long range sound transmission studies. Their approximate locations are shown in Figure 1. The N. E. instrument is a Century Geophysical Corporation 25 cps geophone in a pressure case. It is located in 420 fathoms east of St. David's Island. The S. W. instrument is a moving coil, pressure type, hydrophone located in 165 fathoms south of Gibbs Hill Lighthouse. It has a peak response at 100 cps. Both are connected by submarine cables to beach instrument shacks where the signals are amplified and sent via telephone lines to the Columbia University Geophysical Field Station's main recording room at Cove Point, St. David's. The hydrophone signals are recorded photographically on seismograph type recording drums. For this work the signals were recorded side by side at a paper speed of eight inches per minute. A portion of this recording drum record is shown in Figure 2.

The difference in signal arrival times at these instruments may be used to determine signal arrival bearing. The instruments are 16.2

miles apart representing a baseline of ± 19.8 seconds. This is based on the sound velocity in the surface water of the Sargasso Sea surrounding Bermuda, which is a fairly constant 4980 feet per second the year round.

SHOT DATA FOR CALIBRATION OF ARRIVAL BEARING

To calibrate these two hydrophones for bearing determination purposes a series of shots were fired on an arc of 120 mile radius about Bermuda. These shots were all 1/2# TNT fired by safety fuse at a depth of about fifty feet by the U. S. S. San Pablo in February 1953. The true bearings of these shots relative to Bermuda were from 34° to 221°. The largest angle between any two shots was 2°. The shot and receiving data is given in Table 1. Times being indicated to the nearest minute to identify shots.

DISCUSSION OF ARRIVAL BEARING DETERMINATIONS

The SOFAR signal heard from a TNT charge is a series of staccato burst roughly 6/10 second or less apart, and sometimes followed by reverberation. The number of bursts, their spacing and relative intensity depends upon the shot depth and size, receiving instrument depth and response, the ocean depth, the intervening bottom topography, the range, and the thermal and salinity structure of the intervening ocean. Reverberation is present following the staccato bursts at ranges less tha 200 miles or when the shot, the receiver, or the transmission path is on or adjacent to an island or seamount. Knowledge of all these factors enable one to predict the received signal.

For the ideal case of the mid-latitudes deep sound channel, a shot fired and monitored at the sound channel axis consists of staccato bursts that increase in intensity while the interval between them decreases blending into one loud sound which ceases abruptly. This characteristic abrupt cutoff provides a point in the signal that may be timed to .05 seconds wherever the signal is monitored.

This signal timing accuracy was the basis of the SOFAR air/sea rescue network proposed by Ewing and Worzel (1948) and demonstrated on the West Coast by Lesko, Miller, Condron and McMillian (1950) and Condron (1951). A 4-pound TNT bomb, used as a signal device, could be accurately located by the arrival time of the SOFAR signals at three monitoring stations.

The SOFAR signals received by the Bermuda instruments do not have this characteristic sharp cutoff nor are the signals identical on both instruments. This is caused by their location in different depths of water, both being shallower than the sound channel. It is also caused by their location on dissimilar morphological features along the SE Bermuda island slope. In general their SOFAR signals start with staccato bursts and end with a confused reverberation. Relative timing between signals received at both instruments is done by comparing their overall signal envelope. For convenience, the timing has been done between similarly placed staccato bursts at the beginning of the signal. Figure 2 illustrates a portion of the drum record for signals received from the USS San Pablo shots at a range of 120 miles. Time differences were measured between the arrows as shown.

Figure 3 is a plot of the data from Table 1, the SAN PABLO shots around Bermuda. The dashed curve is the theoretical curve for the system assuming the sound transmission paths lie in a plane surface. For this curve, signal bearings, are the asymptotes of the position hyperbolas. A valid assumption considering the 120 mile range and sixteen mile baseline. It will be noted that the timing method described above has introduced a tendency for the data in Figure 3 to plot in a series of slightly offset straight lines.

Reception of the signals at the two hydrophones is limited by the adjacent topography. Figure 1 shows these limits which are called the cutoffs. The Cove Point hydrophone has a larger arc of reception since it is further offshore and is not shadowed as much by Bermuda.

Figure 4 plots the travel time differences to the Bermuda hydrophones for various azimuths to the southeast. The chart used is HO 1280, Great Circle Sailing Chart of the North Atlantic, the azimuth for each time difference plots as a great circle course or straight line.

ACKNOWLEDGEMENTS

Valuable assistance was received in conducting the event from John I. Ewing of Lamont Geological Observatory, personnel of the U. S. Navy Underwater Sound Laboratory of New London, Connecticut, personnel of the Columbia University Geophysical Field Station, Bermuda and from the officers and enlisted men of the U. S. S. SAN PABLO attached to the Hydrographic Office.

REFERENCES

1. Ewing, Maurice and Worzel, J. Lamar, Long Range Sound Transmission in Propagation of Sound in the Ocean, Geol. Soc. of Am. Memoir 27, 1948.

2. Lesko, J; Miller, M. R.; Condron, T. P.; and McMillian, T.; Triangulation Test of Northeast Pacific Sofar Network, Naval Electronics Laboratory Report No. 175; 27 April 1950.

3. Condron, T. P.; Effect of Sound Channel Structure and Bottom Topography on Sofar Signals, Navy Electronics Laboratory Report No. 233, 14 April 1951.

Shot No.	Date	Shot Time GCT	Azimuth of Shot Location from Cove Point	Time Received GCT		Difference in Arrival Time Seconds	
				Cove Point	High Point	Cove Point Leading High Point	High Point Leading Cove Point
1	20 Feb.						
2	20 Feb.	1250	34	Did not receive			
3	20 Feb.	1256	34.5	Did not receive			
4	20 Feb.	Bad	35.2	Did not receive			
5	20 Feb.	1308	35.7	Did not receive			
6	20 Feb.	No record	36.1	Changing records			
7	20 Feb.	1320	36.5	Changing records			
8	20 Feb.	1326	37.0	Changing records			
9	20 Feb.	1332	37.4	1334			
10	20 Feb.	1338	37.8	1340			
11	20 Feb.	1344	38.3	1346			
12	20 Feb.	Bad	[illegible]				
13	20 Feb.	1356	39.3	1358			
14	20 Feb.	1402	39.[illegible]	1404			
15	20 Feb.	1408	40.1	1410			
16	20 Feb.	1414	40.6	1416			
17	20 Feb.	1420	41.0	1422			
18	20 Feb.	1426	41.5	1428			
19	20 Feb.	1432	42.1	1439			
20	20 Feb.	1438	42.5	1440			
21	20 Feb.	1444	42.9	1446			
22	20 Feb.	1450	43.4	1452			
23	20 Feb.	1456	44.0	1458			
24	20 Feb.	1502	44.5	1504			
25	20 Feb.	1508	45.0	1510			
26	20 Feb.	1514	45.5	1516			
27	20 Feb.	1520	45.9	1522			
28	20 Feb.	1526	46.4	1528			
29	20 Feb.	1532	46.9	1534			
30	20 Feb.	1538	47.3	1540			
31	20 Feb.	1544	47.8	1546			
32	20 Feb.	1550	48.2	1552			
33	20 Feb.	1556	48.7	1558			
34	20 Feb.	1602	49.1	1604			
35	20 Feb.	1608	49.6	1610			

Shot No.	Date	Shot Time GCT	Azimuth of Shot Position From Mid-Point	Time Received GCT		Difference in Arrival Time Seconds	
	1953			Cove Point	High Point	Cove Point Leading High Point	High Point Leading Cove Point
36	20 Feb.	1614	50.0	1616			
37	20 Feb.	1620	50.4	1622			
38	20 Feb.	1626	50.9	1628			
39	20 Feb.	1632	51.4	1634			
40	20 Feb.	1638	52.2	1640			
41	20 Feb.	1644	52.6	1646			
42	20 Feb.	1650	53.8	1652			
43	20 Feb.	1715	54.0	1717			
44	20 Feb.	1730	54.9	1732			
45	20 Feb.	1745	56.0	1747			
46	20 Feb.	1800	57.2	1802			
47	20 Feb.	No record	58.0				
48	20 Feb.	1830	59.0	1832			
49	20 Feb.	1845	60.0	1847			
50	20 Feb.	1900	61.1	1902			
51	20 Feb.	1915	62.2	1917			
52	20 Feb.	1930	63.3	1932			
53	20 Feb.	1946	64.5	Earthquake-masks shot			
54	20 Feb.	No record	65.6	2002			
55	20 Feb.	2015	66.5	2017			
56	20 Feb.	2030	67.7	2032			
57	20 Feb.	2045	68.8	2047			
58	20 Feb.	2100	70.1	2102			
59	20 Feb.	2115	71.2	2117			
60	20 Feb.	2130	72.3	2132			
61	20 Feb.	2145	73.5	2147			
62	20 Feb.	2200	74.8	2202			
63	20 Feb.	2215	75.8	2217			
64	20 Feb.	2230	76.2	2232	2232		
65	20 Feb.	2245	78.2	2247	2247	19.0	
66	20 Feb.	2300	79.2	2302	2302	19.1	
67	20 Feb.	2315	80.5	2317			
68	20 Feb.	2330	81.9	2332	2332	18.6	
69	20 Feb.	2345	83.2	2347	2347	18.6	
70	21 Feb.	0000	84.1	0002	0002	18.2	

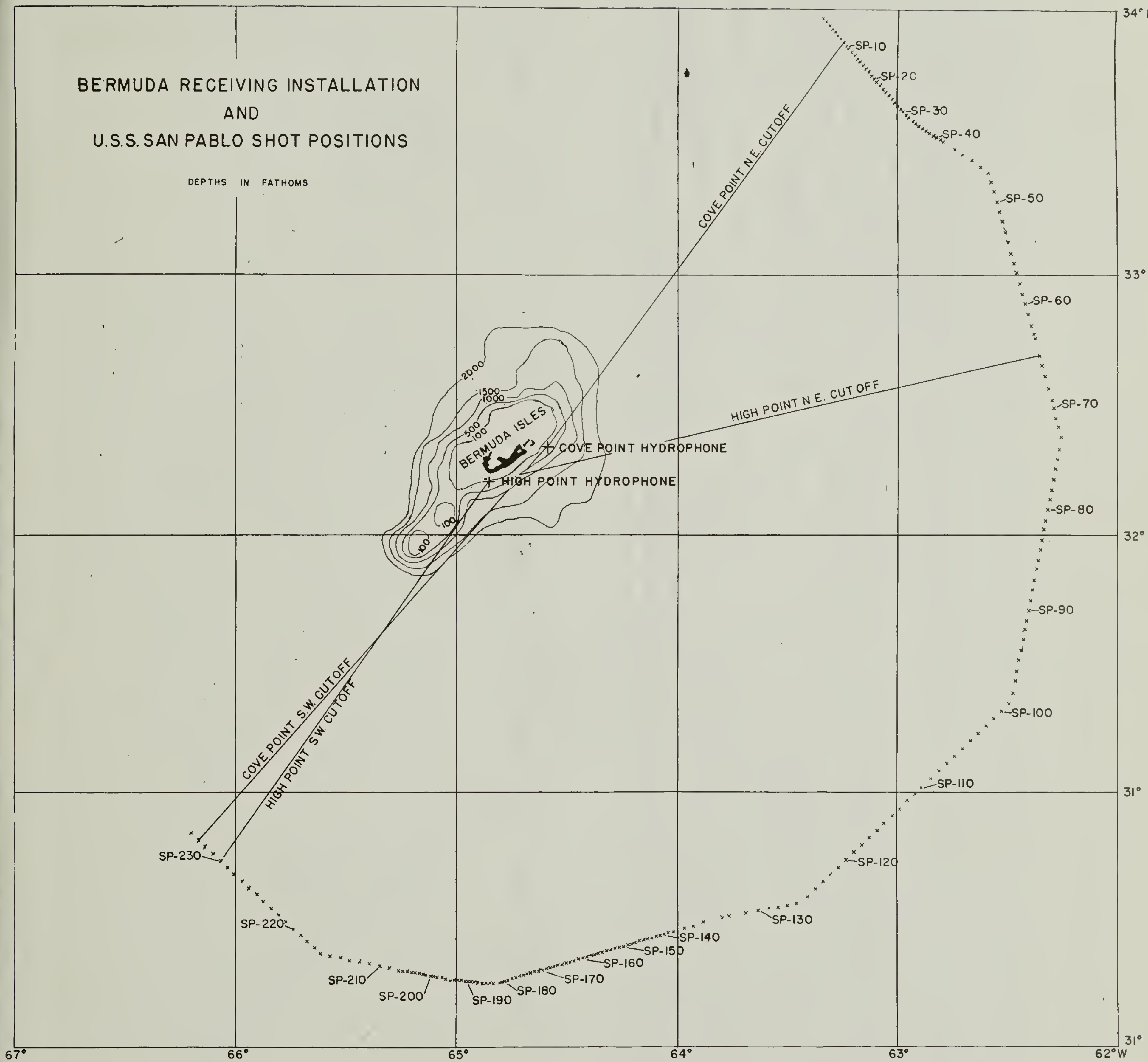
Shot No.	Date 1953	Shot Time GCT	Azimuth of Shot Position From Mid-Point	Time Received GCT Cove Point	Time Received GCT High Point	Difference in Arrival Time Seconds: Cove Point Leading High Point	Difference in Arrival Time Seconds: High Point Leading Cove Point
71	21 Feb.	0015	85.1	0017	0017	17.7	
72	21 Feb.	0030	86.0	0032	0032	17.9	
73	21 Feb.	0045	87.1	0047	0047	17.4	
74	21 Feb.	0100	88.4	0102	0102	17.6	
75	21 Feb.	0115	89.5	0117	0117	17.4	
76	21 Feb.	No record	90.5	0132	0132	16.8	
77	21 Feb.	0145	91.7	0147	0147	17.2	
78	21 Feb.	0200	92.8	0202	0202	17.2	
79	21 Feb.	0215	93.9	0217	0217	16.3	
80	21 Feb.	0230	94.0	0232	0232	Signal in overlap of record	
81	21 Feb.	0245	96.3	0247	0247	16.3	
82	21 Feb.	0300	97.2	0302	0302	Signal in overlap of record	
83	21 Feb.	0315	98.3	0317	0317	15.8	
84	21 Feb.	0330	99.4	0332	0332	15.4	
85	21 Feb.	0345	100.6	0347	0347	15.1	
86	21 Feb.	0400	101.5	0402	0402	14.8	
87	21 Feb.	0415	102.8	0417	0417	14.5	
88	21 Feb.	0430	103.9	0432	0432	14.5	
89	21 Feb.	0445	105.1	0447	0447	13.9	
90	21 Feb.	0500	106.2	0502	0502	13.5	
91	21 Feb.	0515	107.3	0517	0517	13.2	
92	21 Feb.	0530	108.2	0532	0532	12.9	
93	21 Feb.	0545	109.3	0547	0547	12.9	
94	21 Feb.	0600	110.6	0602	0602	12.5	
95	21 Feb.	0615	111.6	0616	0617	12.3	
96	21 Feb.	0630	112.8	0632	0632	11.9	
97	21 Feb.	0645	113.8	0647	0647	12.0	
98	21 Feb.	0700	115.0	0702	0702	11.5	
99	21 Feb.	0715	116.2	0717	0717	11.2	
100	21 Feb.	0730	117.3	0732	0732	10.8	
101	21 Feb.	0745	118.4	0747	0747	Masked by another signal	
102	21 Feb.	0800	119.4	0802	0802	10.9	
103	21 Feb.	0815	120.5	0817	0817	9.7	
104	21 Feb.	0830	121.6	0832	0832	9.5	
105	21 Feb.	0845	122.9	0847	0847	9.2	

Shot No.	Date	Shot Time GCT	Azimuth of Shot Position From Mid-Point	Time Received GCT		Difference in Arrival Time Seconds	
				Cove Point	High Point	Cove Point Leading High Point	High Point Leading Cove Point
106	21 Feb.	0900	123.9	0902	0902	9.0	
107	21 Feb.	0915	125.1	0917	0917	8.1	
108	21 Feb.	0930	126.3	0932	0932	7.8	
109	21 Feb.	0945	127.5	0947	0947	7.3	
110	21 Feb.	1000	128.9	1002	1002	6.9	
111	21 Feb.	1015	130.0	1017	1017	6.6	
112	21 Feb.	1030	131.1	1032	1032	6.3	
113	21 Feb.	1045	132.2	1047	1047	5.7	
114	21 Feb.	1100	133.5	1102	1102	5.4	
115	21 Feb.	1115	134.7	1117	1117	5.1	
116	21 Feb.	1130	135.9	1132	1132	4.8	
117	21 Feb.	1145	137.1	1147	1147	4.2	
118	21 Feb.	1200	138.2	1202	1202	3.9	
119	21 Feb.	1215	139.3	1217	1217	3.9	
120	21 Feb.	1230	140.5	1232	1232	3.3	
121	21 Feb.	No record	141.8	1247	1247	2.9	
122	21 Feb.	No record	143.0	1302	1302	2.4	
123	21 Feb.	1315	144.1	1317	1317	2.0	
124	21 Feb.	1330	145.2	Missed changing record			
125	21 Feb.	No record	146.4	1347	1347	1.2	
126	21 Feb.	1400	147.8	1402	1402	0.9	
127	21 Feb.	1415	148.8	1417	1417	0.75	
128	21 Feb.	1430	149.8	1432	1432	0.3	
129	21 Feb.	1445	150.7	1447	1447	0.0	
130	21 Feb.	1500	151.9	1502	1502		0.1
131	21 Feb.	1515	153.4	1517	1517		0.3
132	21 Feb.	1530	155.2	1532	1532		0.75
133	21 Feb.	1545	156.0	1547	1547		1.6
134	21 Feb.	1600	157.2	1602	1602		1.9
135	21 Feb.	1615	159.4	1617	1617		2.4
136	21 Feb.	1630	160.6	1632	1632		2.7
137	21 Feb.	1645	161.8	1647	1647		3.3
138	21 Feb.	1701	162.5	1703	1703		3.7
139	21 Feb.	Dud					
140	21 Feb.	Dud					

Shot No.	Date	Shot Time GCT	Azimuth of Shot Position From Mid-Point	Time Received GCT		Difference in Arrival Time Seconds	
				Cove Point	High Point	Cove Point Leading High Point	High Point Leading Cove Point
141	21 Feb.	1717	163.4	1720	1720		4.2
142	21 Feb.	1724	163.9	1726	1726		4.2
143	21 Feb.	1730	164.5	1732	1732		4.5
144	21 Feb.	1736	164.9	1738	1738		4.6
145	21 Feb.	1742	165.5	1744	1744		4.6
146	21 Feb.	1748	165.9	1750	1750		4.9
147	21 Feb.	1754	166.5	1756	1756		5.1
148	21 Feb.	1800	167.0	1802	1802		5.2
149	21 Feb.	1806	167.4	1808	1808		5.4
150	21 Feb.	1812	167.8	1814	1814		5.6
151	21 Feb.	1818	168.3	1820	1820		6.1
152	21 Feb.	1824	168.8	1826	1826		5.7
153	21 Feb.	1830	169.4	1832	1832		6.0
154	21 Feb.	1836	169.9	1838	1838		6.1
155	21 Feb.	1842	170.4	1844	1844		6.2
156	21 Feb.	1848	171.0	1850	1850		6.1
157	21 Feb.	1856	171.3	1858	1858		6.4
158	21 Feb.	1900	171.8	1902	1902		6.4
159	21 Feb.	1906	172.2	1908	1908		6.6
160	21 Feb.	No record	172.7	1915	1915		6.9
161	21 Feb.	1918	173.2	1920	1920		7.2
162	21 Feb.	1924	173.7	1926	1926		7.2
163	21 Feb.	1930	174.2	1932	1932		7.3
164	21 Feb.	1936	174.6	1938	1938		7.5
165	21 Feb.	1942	175.2	1944	1944		7.8
166	21 Feb.	1948	175.7	1950	1950		7.8
167	21 Feb.	1954	176.1	1956	1956		7.9
168	21 Feb.	2000	176.5	2002	2002		8.3
169	21 Feb.	2006	176.9	2008	2008		8.1
170	21 Feb.	2012	177.4	2014	2014		8.4
171	21 Feb.	2018	177.9	2020	2020		8.6
172	21 Feb.	2024	178.3	2026	2026		8.8
173	21 Feb.	2030	178.8	2032	2032		8.9
174	21 Feb.	2036	179.2	2038	2038		9.1
175	21 Feb.	2042	179.6	2044	2044		9.3

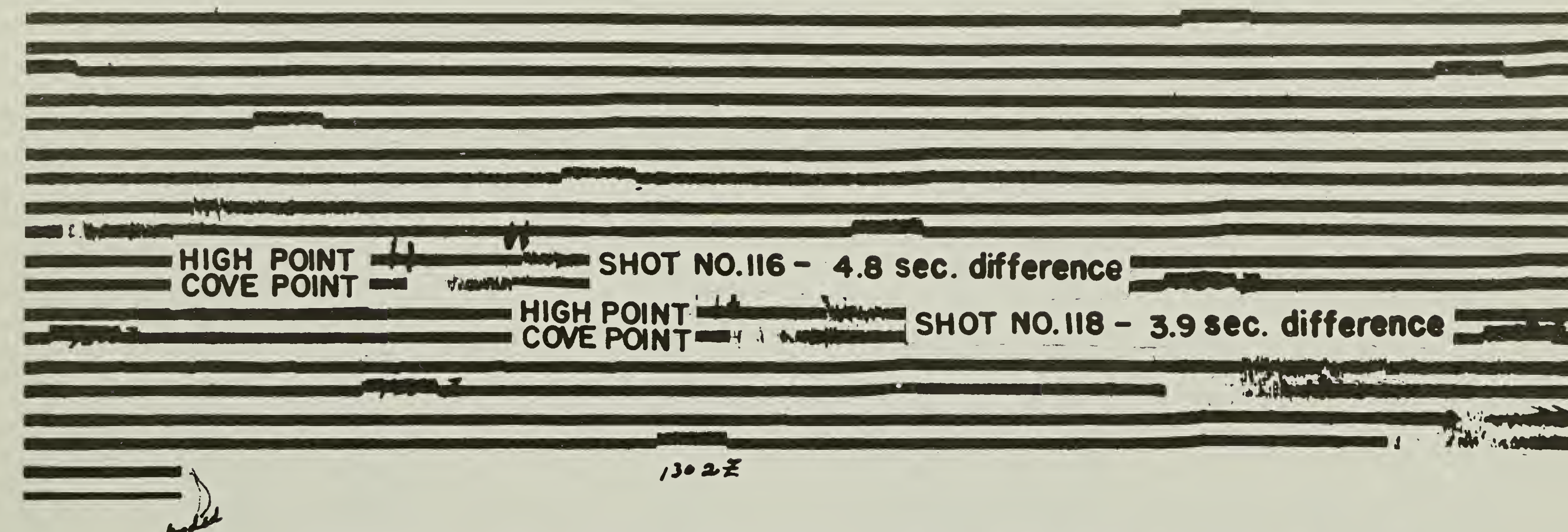
Shot No.	Date	Shot Time GCT	Azimuth of Shot Position From Mid-Point	Time Received GCT		Difference in Arrival Time Seconds	
				Cove Point	High Point	Cove Point Leading High Point	High Point Leading Cove Point
176	21 Feb.	No record	180.0	2050	2050		9.0
177	21 Feb.	2054	180.4	2056	2056		9.3
178	21 Feb.	2100	180.8	2102	2102		9.7
179	21 Feb.	2106	181.3	2108	2108		9.9
180	21 Feb.	2112	181.6	2114	2114		10.0
181	21 Feb.	2118	181.9	2120	2120		10.2
182	21 Feb.	2124	182.3	2126	2126		10.2
183	21 Feb.	2130	182.8	2132	2132		10.3
184	21 Feb.	2136	183.3	2138	2138		10.5
185	21 Feb.	2142	183.7	2144	2144		10.8
186	21 Feb.	2148	184.1	2150	2150		9.8
187	21 Feb.	2154	184.6	2156	2156		10.9
188	21 Feb.	2200	185.0	2202	2202		11.2
189	21 Feb.	2206	185.3	2208	2208		11.1
190	21 Feb.	2212	185.7	2214	2214		11.2
191	21 Feb.	2218	186.0	2220	2220		11.7
192	21 Feb.	2224	186.4	2226	2226		12.1
193	21 Feb.	2230	186.9	2232	2232		12.4
194	21 Feb.	2236	187.2	2238	2238		12.0
195	21 Feb.	2242	187.6	2244	2244		12.0
196	21 Feb.	2248	188.1	2250	2250		11.9
197	21 Feb.	2254	188.6	2256	2256		12.7
198	21 Feb.	2300	189.1	2302	2302		12.7
199	21 Feb.	2306	189.6	2308	2308		12.6
200	21 Feb.	2312	189.8	2314	2314		12.8
201	21 Feb.	2318	190.4	2320	2320		12.9
202	21 Feb.	2324	190.8	2326	2326		13.5
203	21 Feb.	2330	191.1	2332	2332		13.5
204	21 Feb.	2336	191.6	2338	2338		13.7
205	21 Feb.	2342	192.0	2344	2344		13.8
206	21 Feb.	No record	192.4	2351	2351		14.1
207	21 Feb.	No record	192.9	2356	2356		13.8
208	22 Feb.	0000	193.4	0002	0002		14.1
209	22 Feb.	0015	194.4	0017	0017		13.6
210	22 Feb.	0030	195.5	0032	0032		14.3

Shot No.	Date	Shot Time GCT	Azimuth of Shot Position From Mid-Point	Time Received GCT Cove Point	Time Received GCT High Point	Difference in Arrival Time Seconds: Cove Point Leading High Point	Difference in Arrival Time Seconds: High Point Leading Cove Point
211	22 Feb.	0045	196.6	0047	0047		15.3
212	22 Feb.	0100	197.8	0102	0102		14.6
213	22 Feb.	0115	198.8	0117	0117		14.4
214	22 Feb.	0130	199.9	0132	0132		14.9
215	22 Feb.	0145	201.1	0147	0147		14.7
216	22 Feb.	0200	202.2	0202	0202		15.9
217	22 Feb.	0215	203.0	0217	0217		16.1
218	22 Feb.	0230	204.1	0232	0232		16.4
219	22 Feb.	0245	204.9	0247	0247		16.4
220	22 Feb.	0300	206.0	0302	0302		16.7
221	22 Feb.	0315	207.1	0317	0317		16.5
222	22 Feb.	0330	208.2	0332	0332		17.1
223	22 Feb.	0345	200.2	0347	0347		17.1
224	22 Feb.	0400	210.3	0402	0402		17.4
225	22 Feb.	0415	211.4	0417	0417		18.6
226	22 Feb.	0430	212.5		0432		
227	22 Feb.	0445	213.6	Calibration signal masks shot			
228	22 Feb.	0500	214.9	0502	0502		18.3
229	22 Feb.	0515	215.9	0517	0517		19.0
230	22 Feb.	0530	217.0	0532	0532		18.6
231	22 Feb.	0545	218.2	0547			
232	22 Feb.	0600	219.4	0602			
233	22 Feb.	0614	220.4				
234	22 Feb.	0630	221.7				



BERMUDA RECEIVING INSTALLATION
AND
U.S.S. SAN PABLO SHOT POSITIONS
DEPTHS IN FATHOMS
COVE POINT N.E. CUTOFF
HIGH POINT N.E. CUT OFF
COVE POINT S.W. CUTOFF
HIGH POINT S.W. CUTOFF
BERMUDA ISLES
COVE POINT HYDROPHONE
HIGH POINT HYDROPHONE
2000
1500
1000
500
100
SP-10
SP-20
SP-30
SP-40
SP-50
SP-60
SP-70
SP-80
SP-90
SP-100
SP-110
SP-120
SP-130
SP-140
SP-150
SP-160
SP-170
SP-180
SP-190
SP-200
SP-210
SP-220
SP-230
34° N
33°
32°
31°
31°
67°
66°
65°
64°
63°
62°W

Figure 1



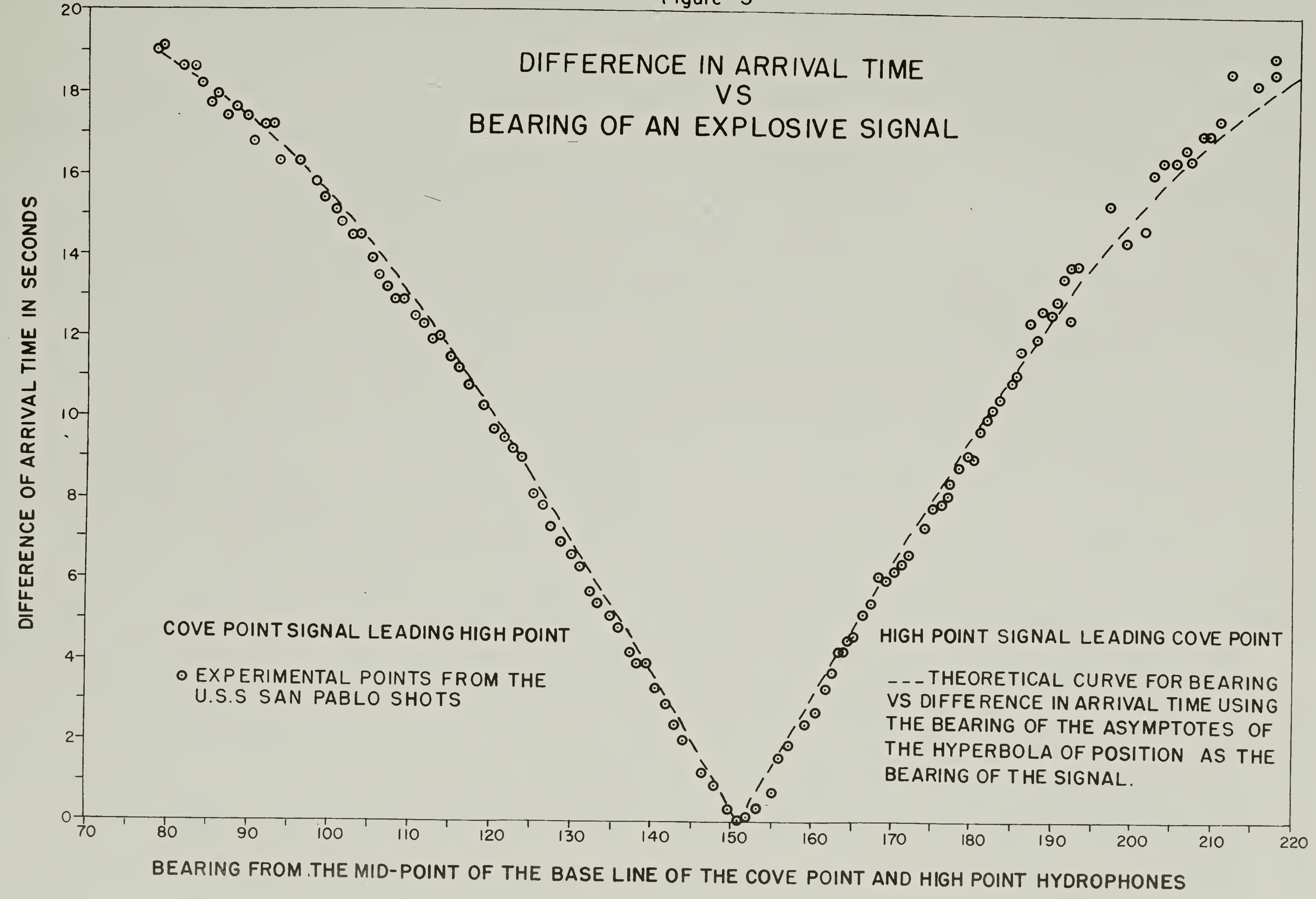
PORTION OF DRUM RECORD FOR U.S.S SAN PABLO SHOTS
21 FEBRUARY 1953

Note the gradual change in the difference of arrival times at High Point and Cove Point for shots illustrated.

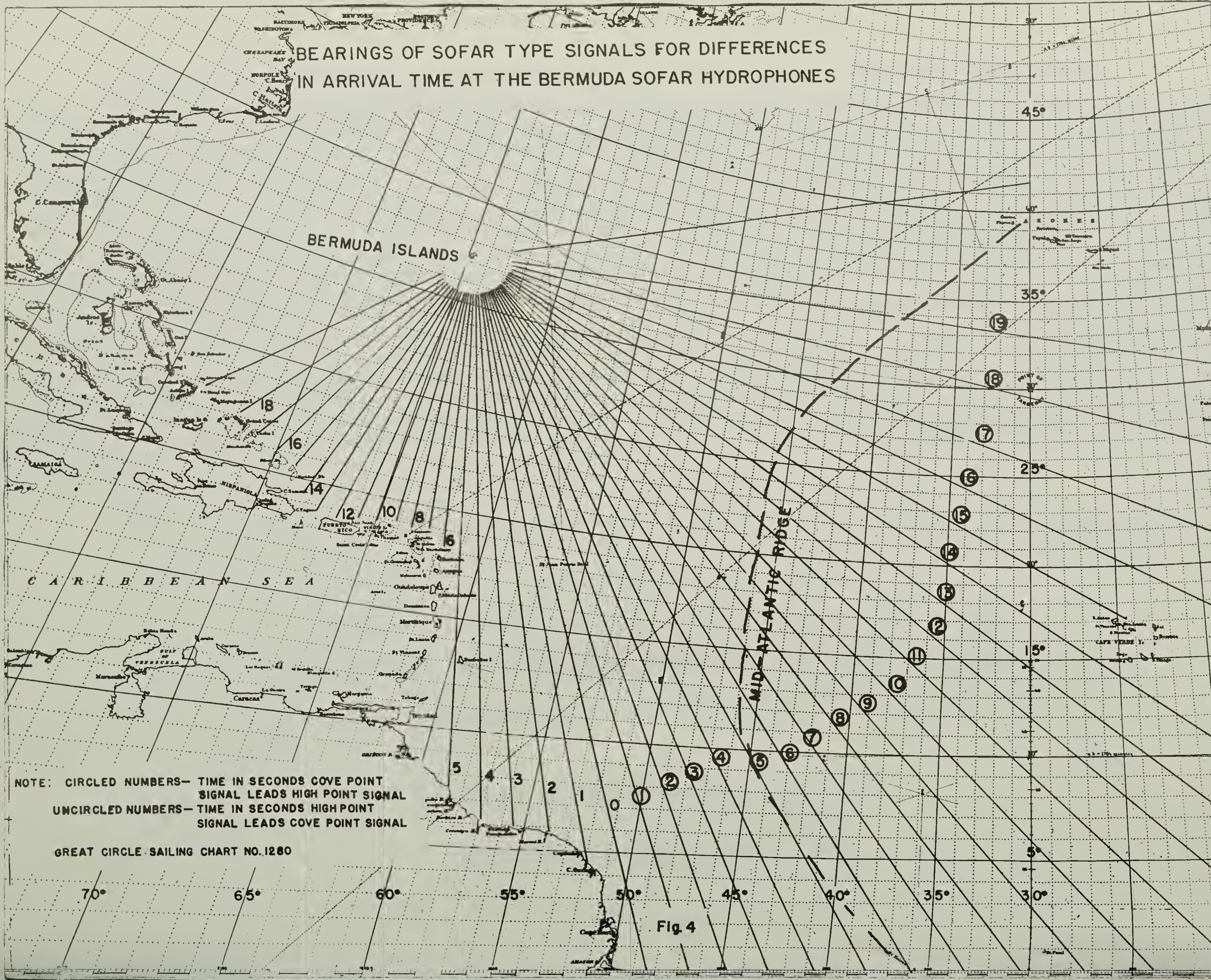
(Even numbered shots 114 to 122)

Fig. 2

Figure 3


DIFFERENCE IN ARRIVAL TIME
VS
BEARING OF AN EXPLOSIVE SIGNAL
COVE POINT SIGNAL LEADING HIGH POINT
EXPERIMENTAL POINTS FROM THE U.S.S SAN PABLO SHOTS
HIGH POINT SIGNAL LEADING COVE POINT
---THEORETICAL CURVE FOR BEARING VS DIFFERENCE IN ARRIVAL TIME USING THE BEARING OF THE ASYMPTOTES OF THE HYPERBOLA OF POSITION AS THE BEARING OF THE SIGNAL.
DIFFERENCE OF ARRIVAL TIME IN SECONDS
BEARING FROM THE MID-POINT OF THE BASE LINE OF THE COVE POINT AND HIGH POINT HYDROPHONES
0
2
4
6
8
10
12
14
16
18
20
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220

BEARINGS OF SOFAR TYPE SIGNALS FOR DIFFERENCES IN ARRIVAL TIME AT THE BERMUDA SOFAR HYDROPHONES



NOTE: CIRCLED NUMBERS— TIME IN SECONDS COVE POINT SIGNAL LEADS HIGH POINT SIGNAL

UNCIRCLED NUMBERS— TIME IN SECONDS HIGH POINT SIGNAL LEADS COVE POINT SIGNAL

GREAT CIRCLE SAILING CHART NO. 1280

Fig. 4